IN SEARCH OF THE USS ALLIGATOR: BATHYMETRY, GEOLOGY, AND SEDIMENTATION OFF THE COAST OF NORTH CAROLINA

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HONORS INDEPENDENT RESEARCH PROJECT

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ABSTRACT

The *USS Alligator* was the first U.S. Navy submarine. It was built during the Civil War by the French inventor Brutus de Villeroi. The Union Navy had hopes that the submarine would aid in destroying the Confederate ironclads. Unfortunately, before proving her merit, the *Alligator* was lost in a storm April 2, 1863 off the coast of Cape Hatteras. By examining the bathymetry, geology, and sedimentation in that area, an accurate model of the ocean floor was produced. Because of North Carolina's narrow continental shelf, it is most likely that the *USS Alligator* is in the deep waters of the continental slope and rise, or even the abyssal plain. Unfortunately, this area will not be easy to search due to its complex pattern of canyons, ridges, and slides. The sediments deposited on the seafloor are mainly silty clay and clayey silt. Although these fine-grained sediments will provide sharp contrast to the metal submarine's profile, they will also complicate the excavation of the wreck. After being disturbed, silt and clay remain suspended in the water column longer than larger sediments, thus greatly reducing visibility. Preparing for these possibilities will aid in creating an efficient and effective search plan to locate the *USS Alligator*.

INTRODUCTION

The United States Navy's first submarine was built in 1861 by the French inventor Brutus de Villeroi. It had a cylindrical shape, was 15 meters long and 2 meters in diameter, with rounded ends and oars protruding on both sides (Terrell and Weirich, 2002). These distinct characteristics resulted in the submarine being christened the USS Alligator. The Alligator was tested multiple times and was deemed seaworthy. In 1862, the oars were replaced with a single screw propeller in order to increase its speed. Unfortunately, the USS Alligator sank off the coast of Cape Hatteras while being towed by the USS Sumpter during a storm on April 2, 1863. The last known position for the vessel was 34.43 latitude and 75.20 longitude (Terrell and Weirich, 2002).

The USS Alligator is an important artifact of naval history. It was the first submarine to have a diver lockout chamber, compressed air to sustain the divers, and an air purification system (Terrell and Weirich, 2002). These unique components qualify the Alligator as the most advanced submarine for its time period, even though it was built before the more famous CSS Hunley. Therefore, finding and raising the Alligator would answer many lingering questions about Civil War technology.

In order to facilitate the search for the Alligator, the geology and bathymetry of North Carolina's coast need to be examined. The most valuable data to begin this search with is from the U.S. Geological Survey (USGS), which mapped the U.S. east coast in 1984 using GLORIA sidescan sonar. This data can be analyzed to determine ocean floor bathymetry, texture, and sediment deposition patterns. Sediment types, sizes, and location, sedimentation rates, and the effects of these on the search efforts should be examined as well. By anticipating the problems that may arise from a complex ocean bottom, the Alligator search will be easier and the chances for success improved.

The GLORIA [Geological Long Range Inclined ASDIC] system uses sidescan sonar technology to obtain images of the seafloor. The first GLORIA prototype was tested in 1969, first proving the system's usefulness (Somers, 1996). Since then, there have been three different GLORIA systems, the Mk 1, II, and III designs. The GLORIA II mapped the U.S. Exclusive Economic Zone in 1984, which produced much of the data and images cited in this paper (Somers, 1996). The raw data is available online (U.S. Geological Survey, 2001d), on CD-ROM (U.S. Geological Survey, 1997), and in a large paper atlas (EEZ-Scan 87 Scientific Staff, 1991). The images collected by the long range sidescan sonar system are employed in determining the geological composition of the ocean floor, creating bathymetric models, and searching for shipwrecks on the seafloor. The GLORIA vehicle consists of a sonar array that sends out sound-waves in a fan-like swath perpendicular to the array's movement (Somers, 1996). The sound pulse is then reflected by the ocean floor and collected by the array. An image is then produced from the data collected. Figure 1 is the GLORIA image of the coast of North Carolina (U.S. Geological Survey, 1997).

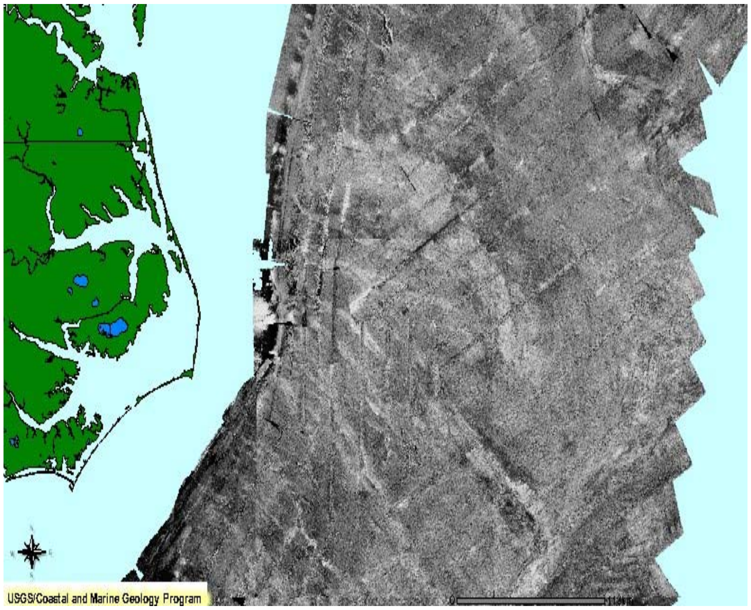

Figure 1. GLORIA image (U.S. Geological Survey, 1997) of coastal North Carolina (strong returns depicted in white).

The strength of the return signal depends on the hardness, roughness or texture, and topography or angle of incidence of the floor. Strong returns are conventionally white or shades of light gray on GLORIA images. Examples of strong returns are scoured bottoms, exposed hard strata, floors and walls of submarine canyons, and flows containing mostly sand and rubble. Weak returns, depicted in black, can be produced by mud, homogenous and soft sediments, and areas of active deposition (Somers, 1996).

Several factors limit the GLORIA system's resolution. First, because the sonar swaths can be up to 60 kilometers wide, the two-way-time time is fairly long. Not only do the sound waves have to travel down to the bottom of the ocean, but after being reflected, they must travel all the way back to the array as well. The signals near the outside of the fan take the longest to return as compared to the ones that are directed more immediately below the array because the outer sound-waves propagate a larger distance (Somers, 1996). The two-way-time length is significant because it determines how often a new swath of sound waves can be sent out. Two swaths cannot be tracked concurrently as the signals would get confused. Because the array is continually being towed forward, the two-way-time delay results in sonar swaths being spaced far apart. To correct this deficiency, the array could be towed slower to reduce the areas not sampled. However, even though this would be more accurate, it will take much longer to cover the area if the array moved slower. Resolution is additionally limited by how wide the sonar fan can be (Somers, 1996). If it is too wide, the pulses will attenuate before reaching the ocean floor or before returning after reflection. Also, if the water is too shallow for the array, the geometry of the signals will skew the image and therefore be ineffective in determining the make-up of the seafloor (Somers, 1996).

GLORIA pixels are 125 meters along track and 50 meters across track (Somers, 1996). Therefore features smaller than about the size of a football field are not discernable. As the *Alligator* was only 15 meters long and about 2 meters in diameter, it would not be visible on GLORIA images. However, the GLORIA sidescan sonar offers the most accurate depiction of the ocean floor available

GLORIA INTERPRETATION OF NORTH CAROLINA'S COAST

The area off the coast of North Carolina was mapped in 1984 during the Exclusive Economic Zone (EEZ) exploration to map the newly defined U.S. territories. The GLORIA II long-range sidescan sonar collected data over 5 cruises, then U.S. Geological Survey (USGS) scientists assembled and interpreted it (Gardner, 1996). From this data, the bathymetry and geology of North Carolina's seafloor could be assessed.

The seafloor off the coast of Cape Hatteras is fairly unique. Three major current systems affect the sedimentation in the area (Popenoe and Dillon, 1996). The south-trending drift brings sediments from north of Cape Hatteras and deposits them either on the shelf or into the Gulf Stream after being turned around by the massive Gulf Stream. The Gulf Stream flows toward the north-east, carrying sediments from the south. The strong current prevents sediments from being deposited on the continental shelf, pushing them onto the continental slope and rise instead. Thus the continental shelf remains sediment starved (Popenoe and Dillon, 1996). The third and most important current in forming underwater bathymetry is the deep western boundary undercurrent (WBUC) that flows south-west beneath the Gulf Stream (Popenoe and Dillon, 1996). The WBUC most directly affects the bathymetric features on the continental slope and rise as it flows closest to the floor.

Because of the high amounts of erosion and sediment transport, the slope off North Carolina has many channels, canyons, and submarine landslides. Figure 2 is an interpretive map from GLORIA of North Carolina’s coast, showing its bathymetry as well as geology of the area (Popenoe and Dillon, 1996).

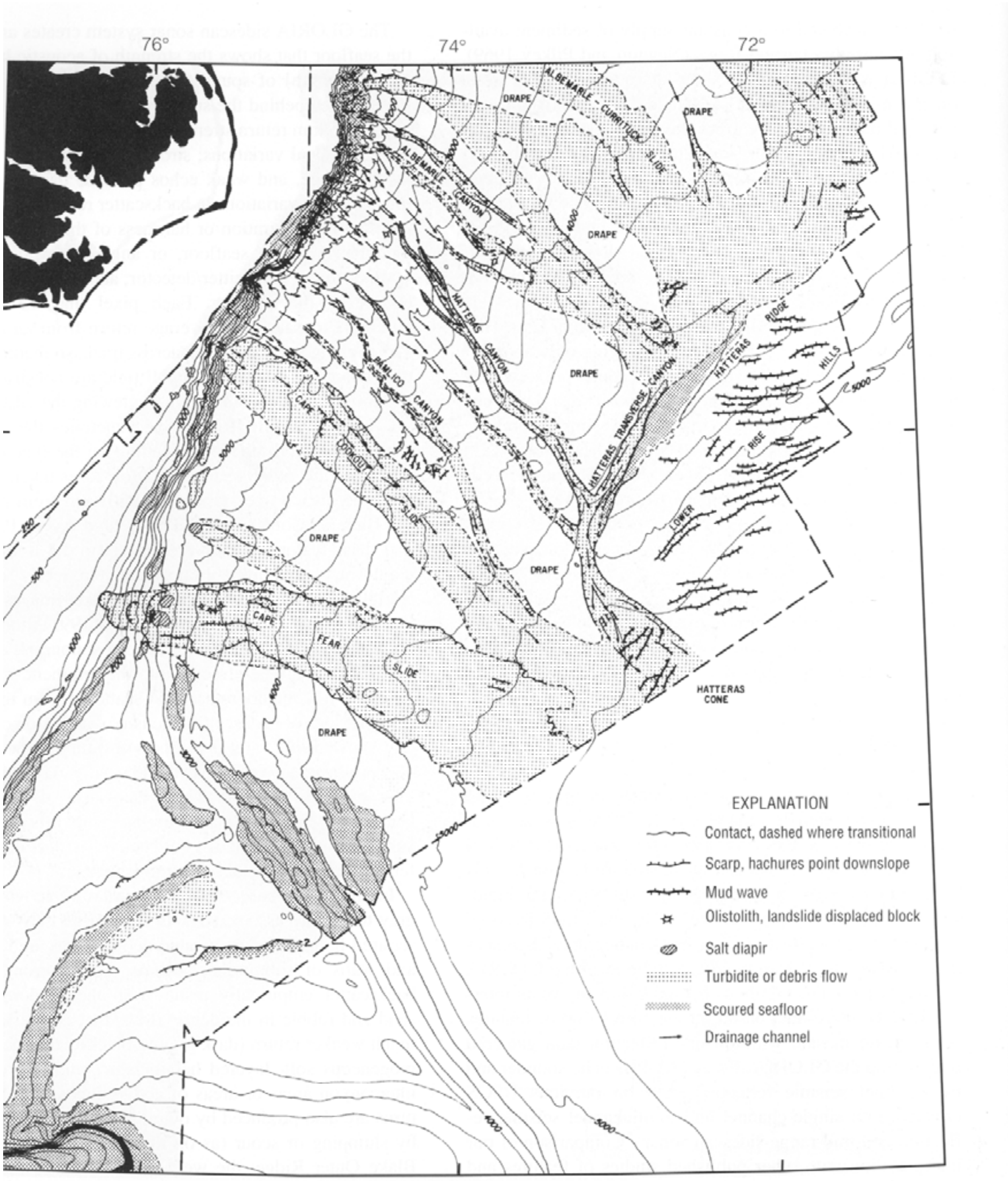

Figure 2. Interpretive map of the continental slope and rise off North Carolina based on the GLORIA mosaic (Popenoe and Dillon, 1996).

In Figure 2, the contour lines become narrow and close together. This represents the continental slope. The continental slope between Cape Hatteras and Cape Lookout is among the steepest in the United States. Not only does its slope average 16°, but there are cliffs and slumps as well.

Northern North Carolina's slope is less steep than off Cape Hatteras, and southern North Carolina has a fairly gentle slope (U.S. Geological Survey, 2001b).

Three main canyons trend perpendicular to the Cape Hatteras coastline (Popenoe and Dillon, 1996). Pamlico is the deepest. It is over 500 meters deep and 5 kilometers wide at some points. Like all of these canyons, it eventually flattens as the continental slope joins the ocean floor. Hatteras Canyon is broad and shallow with a hard scoured surface on the upper rise and blocky rubble on the lower rise and canyon floor. Albemarle Canyon consists of three parallel drainages that merge into one. The other large canyon in the area is the Hatteras Transverse Canyon (U.S. Geological Survey, 2001b). It is 50 meters deep running parallel to the coast and acts as a conduit for northern debris and turbidite movement.

Along with the canyons, the slides and ridges off North Carolina's coast must be taken into account. The Albemarle-Currituck, Cape Fear, and Cape Lookout Slides are wide troughs of rubble and debris (Popenoe and Dillon, 1996). The slides scour the ocean floor, leaving a hard bottom. Some areas have new sediment layers above the scoured floor, and the Cape Lookout Slide has a thick layer of ooze on its hummocky bottom (U.S. Geological Survey, 2001b). The Hatteras Outer Ridge and Blake Outer Ridge have been formed hemipelagic sediments being deposited by the currents. The Blake Outer Ridges is the largest sediment drift known (Popenoe and Dillon, 1996).

SEDIMENTATION RATES

Sediment samples from the Ocean Drilling Program offer data about the sedimentation rates at specified locations near North Carolina. The Ocean Drilling Program drills and recovers cores of rock from the ocean floor. These cores can then be analyzed to determine the thickness of sediments deposited over a certain time period. Unfortunately, as shown by Figure 3, the Ocean Drilling Program has not sampled the seafloor off Cape Hatteras (Paul and others, 2000).

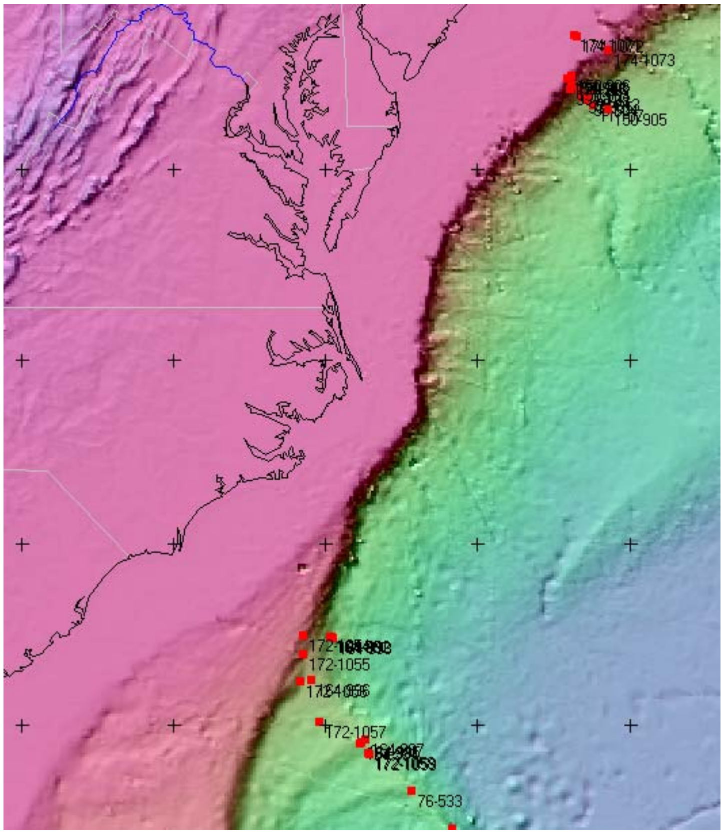

Figure 3. Ocean Drilling Project holes near North Carolina, overlaid on Smith and Sandwell's bathymetric data (1997).

However, there is a group of holes near the southern boundary of North Carolina. These holes, from Leg 172 (Keigwin and Acton, 2001) were drilled to study the geology of the Blake Outer Ridge. By examining these holes, some conclusions can be made about the sedimentation rates off Cape Hatteras. Figure 4 graphs the recent sedimentation rates of holes 1054 to 1063.

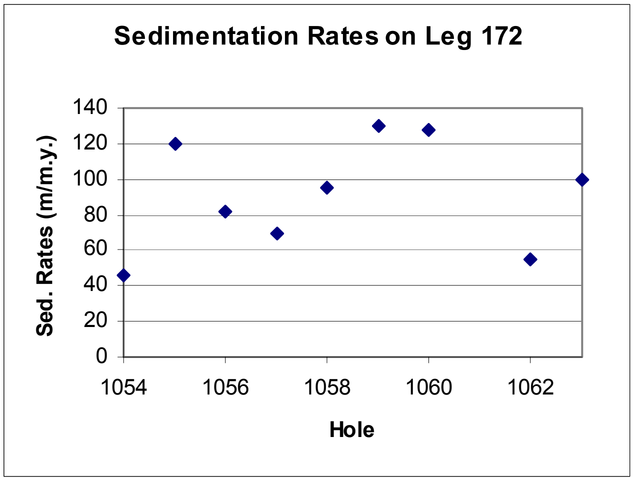

Figure 4. Sedimentation rates (Keigwin and Acton, 2001) at Ocean Drilling Project holes on Leg 172.

The sediments collected from all these holes were from the middle Pleistocene to Holocene epochs (Keigwin and Acton, 2001). The measured sedimentation rates range from 40 to 130 meters per million years. In other words, the site of the *USS Alligator* could have accumulated from 6 to 19.5 millimeters in the 150 years since it sunk. As the largest possible value is still less than an inch of deposition, the accrued sediments should not hinder search efforts for the submarine. Cape Hatteras has complicated current interactions, but most likely sedimentation rates off its coast would be similar to the area sampled by Leg 172.

GLORIA GEOLOGY INTERPRETATION

The bathymetric features on North Carolina's coast influence the types of sediments and the patterns they are deposited in. Figure 5 shows the GLORIA geologic interpretation of the area (U.S. Geological Survey, 2001a).

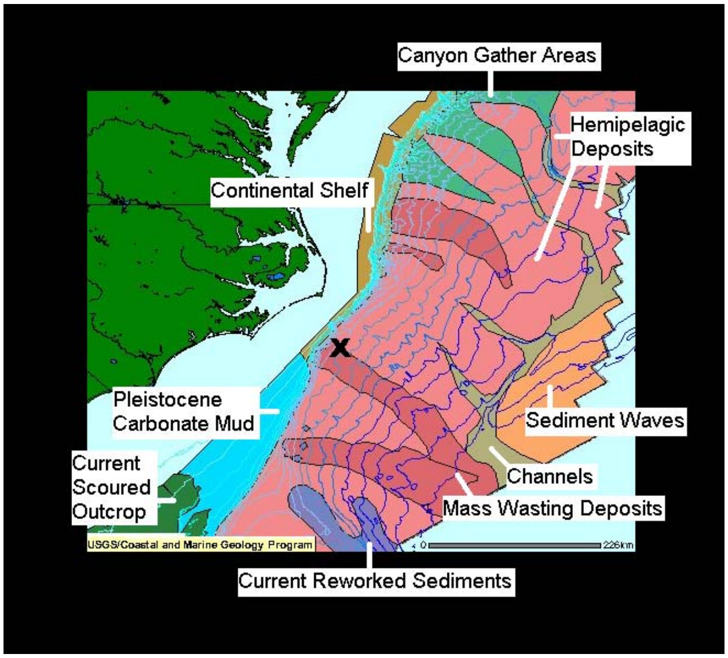

Figure 5. USGS Atlantic Continental Margin GLORIA Geology Interpretation. The large X marks the last known location of the *Alligator*. (U.S. Geological Survey, 2001a).

The mass wasting deposits correlate with the Cape Lookout and Fear Slides discussed above. Between the canyons are hemipelagic deposits, colored in pink in Figure 5. Hemipelagic deposits are terrigenous, fine-grained sediments, consisting mostly of silty clay and clayey silt. The Pleistocene carbonate mud found further south and colored blue, is also composed of fine-grained sediments (U.S. Geological Survey, 2001b). However, the carbonate mud is formed from carbon-based deposits such as animal or plant remains, whereas the hemipelagic deposits originate from land runoff. Sediments waves, marked with orange, are found to correspond to the mouths of the canyons in the continental slope (U.S. Geological Survey, 2001b). The particles that are funneled down the canyons lose momentum and fall out of the water column, therefore forming a fan of sediments on the seafloor. Sometimes the movement of the sediments can be fairly destructive. In 1987, there was a large turbidity flow in the Hatteras Cone (Popenoe and Dillon, 1996). A submarine telephone cable off Cape Hatteras was broken by the surge, so the *Alligator* could have been affected as well. However, it is fairly unlikely that the submarine would have landed in that area as Hatteras Cone is about 300 kilometers south-east of the last fix, and the currents would most likely have pushed the submarine north-east. Nonetheless, the condition of the ocean bottom directly influences the sunken submarine.

SEDIMENT DISTRIBUTION

In order to determine the effects of the marine sediments on the search for the *USS Alligator*, the sediment deposition patterns off North Carolina must be examined. Table 1 lists the size classifications of sediment particles.

Table 1. Wentworth scale for size classification of sediment particles.

Sediment	Grain Size (mm)
Boulder	>256
Cobble	64-256
Pebble	4-64
Granule	2-4
Sand	2-1/16
Silt	1/16-1/256
Clay	<1/256

The ternary diagram in Figure 6 categorizes the sediments off North Carolina's coast (Hastings and others, 2000) according to these classifications.

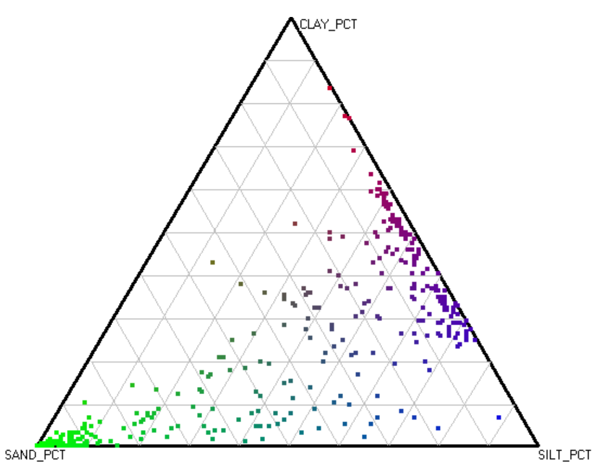

Figure 6. Shepard Ternary diagram of North Carolina Coast sediment samples. Colors green, blue, and red correspond to sand, silt, and clay respectively. All shades between these three colors represent the composition of each sample according to sediment percentage in each sample. (Hasting and others, 2000).

The most dominant sediments are sand, silty clay, and clayey silt. However, it is difficult to distinguish which of these three is most prevalent by simply examining this diagram, as it has no numerical values. Also, the geographical location of the sediments is significant in defining the condition of the ocean bottom where the *USS Alligator* may be located. Therefore, the coast is divided into two regions, on and off the continental shelf. A depth of 500 meters, part way down the continental slope, defines the division between the continental and ocean crust (Open University Course Team, 1991).

The Shepard ternary diagram plots sand, silt, and clay in an equilateral triangle according to the percentage of each sediment in a sample (Poppe and others, 2000). If a sample consists wholly of sand, it is plotted in the bottom left corner of the triangle. Silt and clay are in the bottom right corner and top corner, respectively. The exact middle of the diagram represents a sample comprised of equal amounts of the three sediments. Similarly, a sample at the midpoint of one side of the triangle is half one sediment and half the other. In order to facilitate analyzing the diagram, a range of colors are used to classify the samples as well. Sand, silt, and clay are represented as green, blue, and red marks. Therefore, a point halfway between silt and clay is purple. The various shades of colors specifically aid in identifying the composition of each sample when the samples are plotted on a map. The following figures demonstrate the usefulness of these techniques.

Figure 7 classifies the sediments collected in greater than 500 meters of water. It is apparent that the silty clay and clayey silt are the prominent sediments in the deeper water.

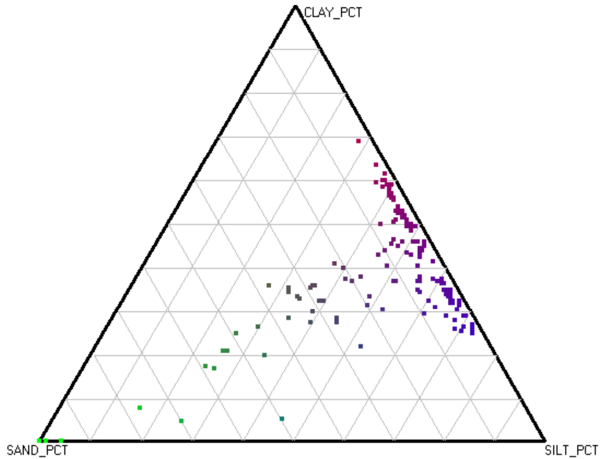

Figure 7. Ternary diagram of North Carolina sediment samples (Hasting and others, 2000) at depths greater than 500 meters. Colors correspond to initial ternary diagram's relationships.

Figure 8 plots the sediments geographically along the coast; the small number of sandy samples occur in the southern part of the area, on the Blake Plateau.

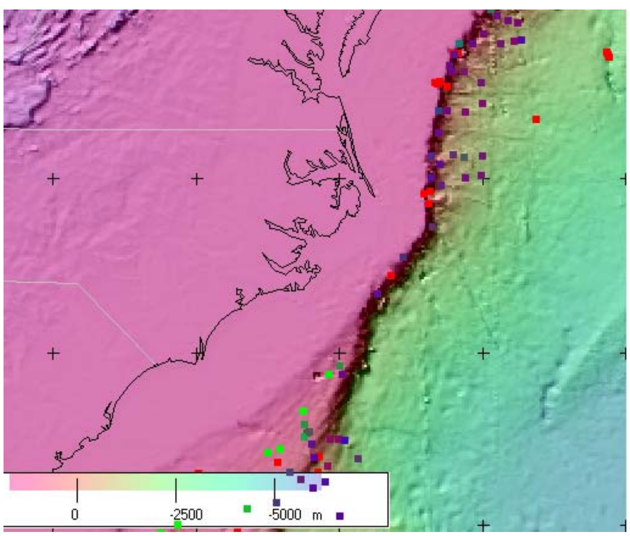

Figure 8. Geographic and bathymetric location (Smith and Sandwell, 1997) of sediment samples (Hasting and others, 2000) at a depth of greater than 500 meters. Colors correspond to relationships of Figure 1.

The darker red and purple points in Figure 8 mark the silty clay and clayey silt sediments on the continental slope and abyssal plain. These finer grained sediments are carried further from land by the currents because of their longer suspension time. It takes much longer for silt and especially clay to fall out of the water column than it does for the larger sand particles. Therefore, sand is deposited closer to the shore, as depicted by Figure 9.

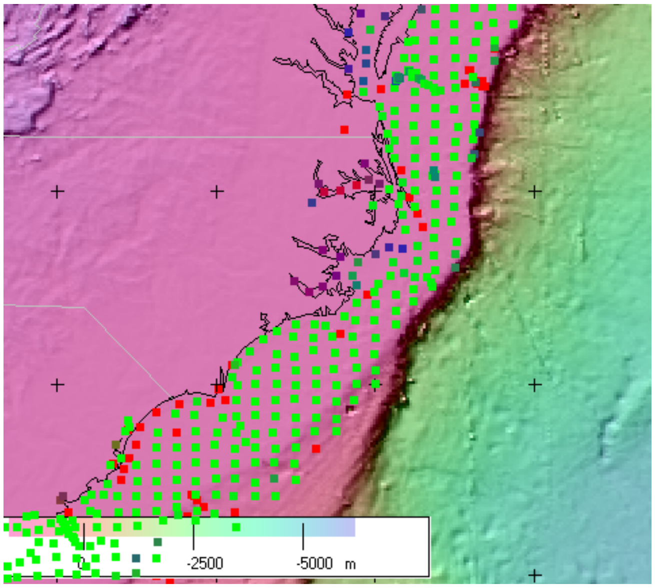

Figure 9. Geographic and bathymetric location (Smith and Sandwell, 1997) location of sediment samples (Hasting and others, 2000) at a depth of less than 500 meters.

There is a large concentration of green marks on the continental shelf and in shallower waters, representing the sand deposits. The ternary diagram in Figure 10 supports the prevalence of sandy sediments as well.

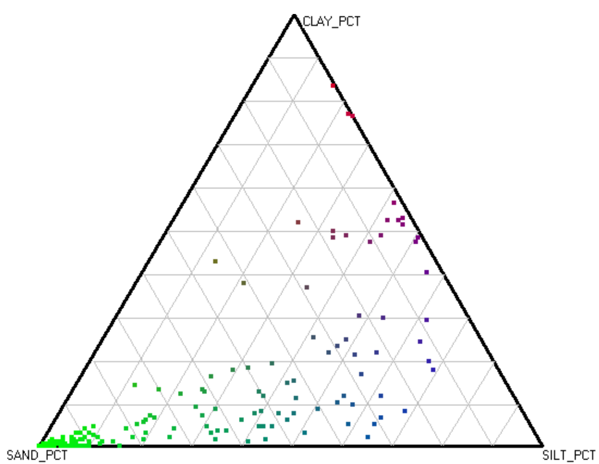

Figure 10. Ternary diagram of North Carolina sediment samples (Hasting and others, 2000) at depths less than 500 meters.

Because there are relatively few sediment samples off the coast of North Carolina, the sedimentation patterns along the entire east coast were also examined. Figure 11 illustrates the consistency of the east coast's sediment distribution with the North Carolina results discussed above.

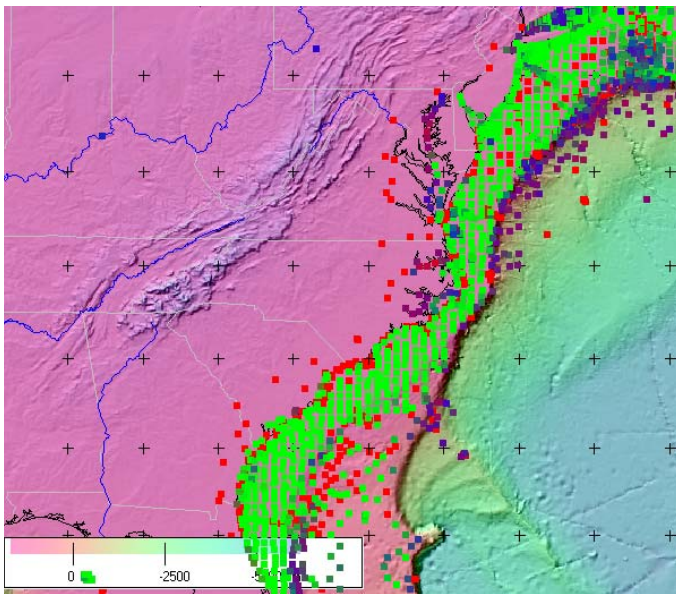

Figure 11. Geographic and bathymetric location (Smith and Sandwell, 1997) - of sediment samples (Hasting and others, 2000) along the east coast of the United States.

Therefore, it can be assumed that sand will be the main sediment in on the continental shelf, and the smaller grained silty clay and clayey silt will dominate deep water sediments. However, in order to reaffirm this assumption, the data set from Hasting and others (2000) was analyzed by a different method. The amount of each sediment in a sample was plotted against the depth of the ocean floor. The graph in Figure 12 summarizes these results.

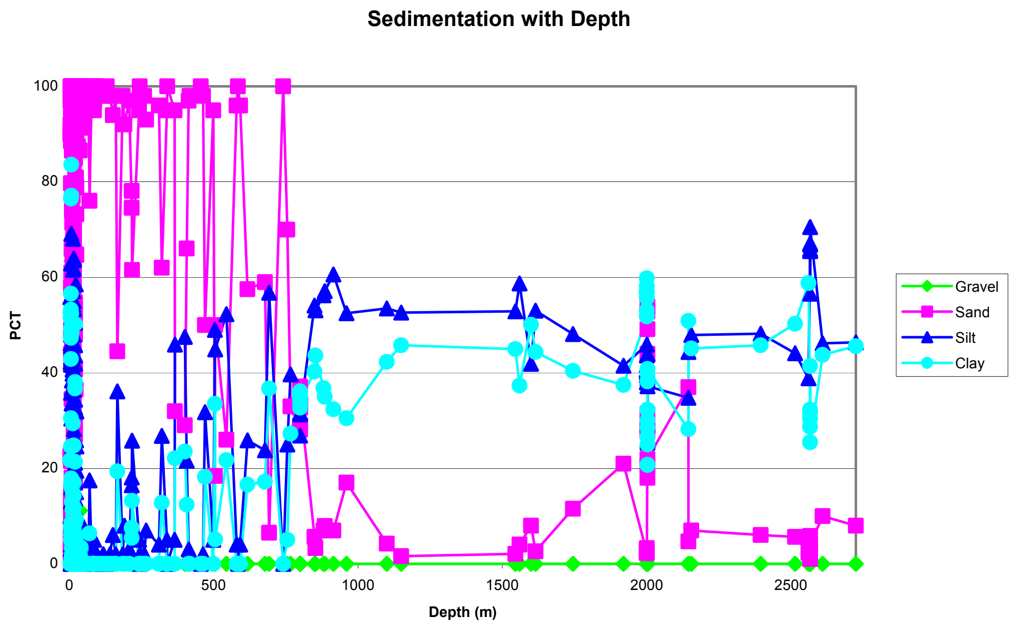

Figure 3. Graph of sedimentation of gravel, sand, silt, and clay according to depth.

Again, it is apparent that sand is dominant in the shallow water, even up to 750 meters deep. However, after that point, there is very little sand compared to the amount of silt and clay accumulated. Gravel, as expected, is present only in trace amounts even in the shallow depths. These larger sediments fall out of the water column in rivers and near shore as soon as the currents are no longer fast enough to support their weight.

DISCUSSION--SEARCH APPLICATIONS

The sediments off the coast of North Carolina are essential to the search for the *USS Alligator*. The fine-grained sediments on the continental slope, rise, and abyssal plain will provide a sharp contrast for the missing submarine. The tiny particles will absorb the energy sent from the sidescan sonar and therefore produce a small return to the device. A metal boat on top of these sediments however, will strongly reflect the signals and produce a large spike of energy against a weak background. Unfortunately, the trade-off for the sharp return is that the

Alligator would be in water so deep that it would be difficult if not impossible to recover. The sand on the continental shelf conversely, would have less contrast between its return and the submarine's because it is harder and reflects the sound more. It would still be possible to identify the submarine's signal though, and recovery would be much simpler if the *Alligator* was discovered on North Carolina's continental shelf. Sandy sediments on the shelf would make working in the water less complicated. Instead of stirring up easily and limiting visibility like silt and clay, sand settles out of the water column fairly quickly. Therefore, divers could easily recover artifacts from the submarine.

Unfortunately, detection and excavation of the *Alligator* would not be as simple if the submarine is at the bottom of a canyon or near a ridge. The complex arrangement of interconnected canyons, ridges, and slides on the continental slope is difficult to search thoroughly. Plus, sediments are continually being deposited in this area. They drift downslope of the ridges and could prevent the 150 year old submarine from being detected. Therefore, although it is unlikely the submarine would be near the shoreline because of the northeasterly flow of the predominant Gulf Stream, the flat, shallow ocean bottom would be much easier to search than the irregular seafloor further off the coast.

Search tactics for the *Alligator* depend on where the boat landed on the ocean bottom. If it is on the continental shelf, more conventional methods may be employed. The *USS Monitor's* turret was recently recovered 32 kilometers off the coast of Cape Hatteras (NOAA, 2002). Because the wreck was only 73 meters deep, divers were able to assist in the excavation (The Mariners' Museum, 2002). Still pictures, video, sidescan sonar, and remotely operated vehicles were also utilized to examine the *Monitor* (NOAA, 2002). Another system that was used to study the *Monitor's* condition is a new deep sea sonar built by David Mindell and his research group from the Massachusetts Institute of Technology Program in Science, Technology, and Society (Deeparch, 2003b). It is a high frequency, narrow beam sub-bottom profiler. The novelty of this system is that its focused sound beams reveal a picture of the ship structure that is either buried or unseen underneath other ship elements. The sub-bottom profiler allows layers to be removed from the 3-dimensional detailed image it produces in order to examine features beneath (Deeparch, 2003b). This technology has been used to survey the wrecks of the *CSS Hunley* and *USS Defense*, but is not applicable to only shallow water wrecks (Deeparch, 2003a). The sub-bottom profiler would be a useful tool regardless of the depth of the water the *USS Alligator* is sunk in. However, it would not be helpful in searching for the submarine because its sound band is too narrow. Instead, it would be employed to map the wreck site after it has been found.

Other search vehicles that could be used in deep water off the continental shelf would be autonomous underwater vehicles (AUV), remotely operated vehicles (ROV), and the U.S. Navy's advanced tethered vehicle (ATV) (Deeparch, 2003a). The ATV was used to search for the *USS Yorktown*, finding it in the Pacific Ocean, 5 kilometers underwater. Some of the vehicles may carry a multibeam sidescan sonar that uses several fans of sound waves instead of a single conventional fan (Deeparch, 2003a). This improvement doubles the speed of sampling. Any of these systems could help in the search for the *Alligator*, but expenses and availability would have to be taken into account as well.

MILITARY APPLICATIONS

The geology of the ocean floor off the coast of North Carolina is not only applicable to searching for the *USS Alligator*, but is valuable to the Navy as well. The Navy is interested in locating the Civil War submarine for historical purposes, but an analysis of the ocean floor will aid the modern Navy in everyday operations. The Navy is constantly concerned with bathymetry as submarines and ships continually transit both shallow and deep waters. The goal of the Naval Meteorology and Oceanography Command is to “ensure the safe navigation of all United States' ships…and promote efficiency and safety for all who use the world's ocean highways” (Naval Meteorology and Oceanography Command Public Affairs, 2002). A mistake in the depth of the ocean bottom could result in a grounded ship or a damaged submarine. Therefore, the military uses survey ships, unmanned vehicles, and aircraft to obtain data for mapping, charting, and marine acoustics. Sidescan sonars similar to the GLORIA used in the EEZ survey map ocean floors throughout the world to obtain greater battle-space awareness. Similar sonar technology is employed by submarines for navigation. According to the Naval Oceanographic Office (NAVOCEANO), studying the ocean’s bathymetry and geology is vital to meeting “the U.S. Navy and Department of Defense safe navigation and weapon/sensor performance needs” (NAVOCEANO, 2002).

CONCLUSION

The coast of North Carolina can be divided into two main sections, on and off the continental shelf. The continental shelf is considered to be the flat, sandy seafloor less than 500 meters deep. The *USS* Alligator would be less difficult to find and recover in this shallow region. However, the most likely location of the submarine is in the deeper, more irregular seafloor off of the continental shelf. The continental slope is broken by deep canyons both perpendicular and parallel to the coastline. Slides, slumps, and ridges further complicate the area. Although the fine-grained silt and clay will make the metal submarine conspicuous to sonar imaging, it will also stir up and shift more easily during excavation operations. As the deep water will already be difficult to work in, these complications compound. Therefore, the hope is that the *USS Alligator* landed somewhere closer to the North Carolina shore.

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